MOLDED ELECTRONIC COMPONENTS

This application claims the benefit of U.S. Provisional Application Serial No. 60/401,133, entitled "Molded Electronic Components," filed August 5, 2002, the entire contents of which are hereby incorporated by reference.

Field of the Invention

This invention relates to techniques for manufacturing electrical components. For instance, these techniques may be used to make molded equalizers for use with communications equipment, particularly for use in amplifiers, fiber optic nodes, and head-end equipment in cable television (CATV) systems. These techniques may also be used to manufacture AC bypass coils or filters, cable simulators, surge protectors, diplex filters, and other plug-in devices common to broadband amplifiers, fiber optic nodes, and head-end equipment used in the CATV industry.

Background of the Invention

Cable television (CATV) and other communications systems use many electronic components. An example of one such component is the equalizer. Equalizers are used by the CATV industry to correct for signal loss that occurs as signals flow through the long lengths of coaxial cable, strung between telephone poles or buried underground, to various points where consumers are then able to access the signals. Coaxial cable offers some finite loss to the signals transmitted through it. In other words, if signal is injected at 100% power at one end at all frequencies, less than 100% of that signal will be recovered from the other end of the cable and varies depending on the frequency. The loss associated with the coaxial

cable is not the same at all frequencies, and the loss typically increases as frequency increases. The result is that, after passing through a length of cable, the spectrum of radio frequency ("RF") signals is stronger at low frequencies and weaker at high frequencies due to cable loss, which is known as signal slope. It is harder to process a full signal spectrum with the lower frequencies stronger than the higher frequencies. Preferably, it is desirable that all frequencies are at essentially the same level in terms of signal strength, which is known in the communications industry as a flat spectrum.

Amplifiers, fiber optic nodes, and head-end equipment are utilized in CATV systems, and most utilize a removable equalizer. As applied to the CATV industry, an equalizer is typically a plug-in device used to adjust the desired slope of a cable signal of an RF broadband signal in amplifiers, fiber optic nodes, and head-end equipment. An equalizer, as used in an amplifier, is typically a passive R-L-C (resistor-inductor-capacitor) circuit designed with a response signature that negates, or flattens, a corresponding amount of coaxial cable loss for various operating frequencies. Referring back to the spectral analogy above, the signal spectrum exiting a length of coaxial cable generally has a stronger signal level at lower frequencies than higher frequencies. The signals are routed through an equalizer of appropriate value for the given cable length. Typically, the equalizer does not adjust the "lower" power or signal levels at the higher frequencies but rather attenuates the "higher" signals found at the lower frequencies to create a flat frequency spectrum. This means that all frequencies are about the same amplitude as a result of being routed through the equalizer.

Previous equalizers, such as the equalizer shown in Figs. 1A and 1B, generally include a printed circuit board with components (such as resistors, inductors, and capacitors)

mounted on the board and contact pins exiting the circuit board. The equalizer plugs in to its host unit, for example, a CATV amplifier, by insertion of the pins into corresponding sockets on the host unit. The friction between the pins and sockets holds the equalizer in place, but the delicate electronic components are left exposed. This is a problem because each equalizer has different operating characteristics and movement of the circuit elements could cause those characteristics to change.

In the electronics industry, it has long been known that one can encapsulate certain active circuit components in plastic or similar materials to add robustness and protection to the circuit. For instance, integrated circuit makers like VLSI and LSI have obtained U.S. Patent Nos. 5,448,825 and 5,570,272, respectively, for methods and apparatuses for encapsulating integrated circuits. Indeed, the art of encapsulating integrated circuits is quite advanced, with patents being awarded on the particular materials for encapsulating the integrated circuits, such as U.S. Patent No. 6,030,684, or on materials with particular thermal characteristics, such as the material described in U.S. Patent No. 5,909,915.

While active, integrated circuits have long been encapsulated, passive circuits like equalizers have not been. The encapsulating material itself would modify the operating characteristics of these circuits by effectively adding capacitance to the circuit. Yet applications for these circuits often require very precise operating characteristics. Indeed, to allow service personnel to adjust an equalizer to match the required field conditions, tunable equalizers were developed with removable, snap-on covers, as shown in Figs. 2A and 2B. Figs. 3A-3C show a non-tunable, double-sided equalizer with a snap-on enclosure, although open areas remain between the cover and the substrate holding the circuit elements.

The advantage of such tunable equalizers or covered equalizers is that they allowed for re-tuning of the circuit if necessary and/or provided some protection of the circuit to maintain the equalizer's desired operating characteristics. But disadvantages abounded. The circuit elements remained relatively exposed, the products were harder to manufacture given their small sizes and consequent small profiles. The snap-on covers or enclosures are manufactured separately from the circuit, and attached to the completed circuit at some late stage in the manufacturing of the equalizer. The snap-on cover does not physically touch the circuit components because it would impact the electrical circuit, but the cover often touches the edges of the circuit board. Although providing some cover and protection to the equalizer circuit, the snap-on plastic cover is problematic because the cover can come off or shift physically on the circuit and give the equalizer a flimsy feel. Additionally, if the cover contacts the circuit, it may change the performance of the equalizer.

Accordingly, there is a need for an equalizer that is more robust and easily handled such that the electronic components of the circuit are adequately protected and do not require periodic tuning.

Summary of the Invention

The present invention provides a molded passive circuit. The circuit is designed to have a first set of operating characteristics. After molding, the circuit interacts with the molding material to create a component that operates at a second set of operating characteristics that are the desired characteristics for the component part. By designing the circuit to account for the impact of the encapsulating material upon the performance of the circuit, a robust but precise electronic component may be created.

In one embodiment, the component is an equalizer designed for interface with CATV or other communications equipment, particularly predetermined locations in amplifiers used in CATV systems. An exemplary molded equalizer generally includes an injection-molded housing encapsulating an equalizer circuit and with pins protruding from one end. The equalizer circuit is a passive R-L-C circuit. The housing and pins are designed for interface with predetermined locations in CATV amplifiers. Certain exemplary embodiments are two-port devices, with an input, an output, and ground, and are typically used in a 75-ohm environment.

In an exemplary embodiment, injection molding is used to inject molten plastic into a cavity around the equalizer circuit and the board on which the circuit is mounted. The plastic then hardens and encapsulates the circuit and the board. The injection-molded housing and the circuit are one inseparable piece, and the final product is extremely robust and leaves no portion of the electronic components of the circuit exposed in any way. The addition of the plastic changes the performance of the equalizer circuit, requiring pre-mold adjustments to be made in order for the molded equalizer to have the desired operating characteristics. The housing acts as an additional capacitor. Prior to addition of the injection-molded housing, the equalizer circuit is designed to anticipate the effects of the addition of the housing because the housing becomes a part of the circuit.

The present invention also includes methods for manufacturing robust, but precise passive circuit components. The method generally includes: designing the circuit to operate at a first set of operating characteristics; encapsulating the circuit in a particular material, such as plastic, resin, or the like; retesting the encapsulated circuit to determine a second set of operating characteristics; and, if necessary, modifying the design of the circuit to account

for the effect of the encapsulating material so that the overall encapsulated component performs at a predetermined set of operating characteristics.

Accordingly, the present invention aims to achieve one, more, or combinations of the following objectives: to provide a robust, but precisely tuned electronic component such as an equalizer; to form a robust passive circuit component by encapsulating the circuit in a protective material; and to tune an equalizer or other circuit to account for the effects of an encapsulant surrounding the circuit.

Brief Description of the Drawings

Figs. 1A and 1B show front and top views, respectively, of a coverless prior art equalizer.

Figs. 2A and 2B depict top and side views, respectively, of a partially-covered prior art equalizer.

Figs. 3A, 3B, and 3C illustrate top, front, and side views, respectively, of a prior art equalizer with a snap-on cover.

Figs. 4A and 4B show an un-molded and molded equalizer according to the present invention.

Figs. 5A-5E show back, front, side, bottom, and top views, respectively, of a molded equalizer according to certain exemplary embodiments of the present invention.

Fig. 6 illustrates frequency (MHz) versus insertion loss (dB) for an exemplary 2.0 dB equalizer.

Fig. 7 illustrates frequency (MHz) versus insertion loss (dB) for an exemplary 3.0 dB equalizer.

Fig. 8 illustrates frequency (MHz) versus insertion loss (dB) for an exemplary 4.0 dB equalizer.

Fig. 9A shows frequency (MHz) versus input return loss (dB) for both un-molded and molded exemplary 2.0 dB equalizers.

Fig. 9B shows frequency (MHz) versus output return loss (dB) for both un-molded and molded exemplary 2.0 dB equalizers.

Fig. 10A shows frequency (MHz) versus input return loss (dB) for both un-molded and molded exemplary 3.0 dB equalizers.

Fig. 10B shows frequency (MHz) versus output return loss (dB) for both un-molded and molded exemplary 3.0 dB equalizers.

Fig. 11A shows frequency (MHz) versus input return loss (dB) for both un-molded and molded exemplary 4.0 dB equalizers.

Fig. 11B shows frequency (MHz) versus output return loss (dB) for both un-molded and molded exemplary 4.0 dB equalizers.

Detailed Description of the Invention

Before further describing a particular implementation of the present invention that is shown in the drawings, the following terms are explained, although more thorough understanding of the terms can be reached by resorting to this entire document. These term explanations are not intended to be conclusive, as technology will change and skilled persons will recognize other ways to implement the same functionality. The term "housing" includes any casing, shell, or member that is formed such that at least a portion of the housing encapsulates the electrical components of the equalizer circuit. Pins includes any prong(s),

plug(s), connector(s), tube(s), wire(s), or other member that may be inserted into a socket, jack, or other opening or any electrical member that may be electrically coupled to a socket, jack, or other opening whether or not physical contact is made. The embodiments described herein may interface with a predetermined location in CATV or other communications equipment, for example a predetermined location in an amplifier used in CATV systems.

An exemplary embodiment of a molded equalizer is shown in Figs. 4B and 5A-5E. Figs. 4A and 4B show both an un-molded equalizer and a molded equalizer for reference, as well as for comparison with the prior art equalizers shown in Figs. 1A-3C. An exemplary molded equalizer with approximate dimensions, in inches, is shown in Figs. 5A-5E.

As shown in Figs. 5A-5E, a molded equalizer 20 includes pins 22, 24, and 26 that extend from a bottom end of a housing 28. In the exemplary embodiment shown, pins 22 and 24 are spaced approximately 0.15 inches apart, while pins 24 and 26 are spaced approximately 0.20 inches apart. The spacing of the pins is based on the predetermined location with which molded equalizer 20 is designed to interface (e.g., an amplifier in CATV systems). In the exemplary embodiment shown in Figs. 5A-5E, pin 22 or 24 is input, pin 24 or 22 is output, and pin 26 is ground. As shown in Fig. 5E, a dB value of molded equalizer 20 is hot-stamped on the top of molded equalizer 20 (in this case, 0.5 dB). Equalizers typically have dB values ranging from 0 to 26 dB, and the characteristic impedance for the majority of equalizers is 75 ohms.

Equalizers are used in the CATV industry to compensate for loss resulting from the use of coaxial cable to transmit RF signals from a CATV trunk station to a subscriber's home. This loss increases with the length of cable, as well as with the frequency transmitted. The loss is not linear but has its own shape. Each coaxial cable manufacturer calculates the

loss of its cable. The function of an equalizer is to "equalize" (i.e., create the same amplitude or loss at all frequencies) the signal coming into the amplifier. The equalizer circuit may be a passive circuit, taking the low amplitude of the incoming signal and flattening the signal below that point before the signal is transmitted to the rest of the cable amplifier. Equalizers of varying dB values are used because CATV amplifiers are located at varying distances from the trunk system (i.e., the length of coaxial cable through which the signal travels is not always the same).

Figures 6-11C depict a sweep in frequency (in MHz) versus loss (in dB) for three different exemplary equalizer values. On the frequency axis (x-axis), the scale is linear from 5 to 900 MHz, which is the bandwidth used in the CATV industry. On the loss axis (y-axis), the scale is –50 to 0 dB for figures showing input and output return loss (Figs. 9A-11B). For insertion loss, the scale runs from –4 to 0 dB (Figs. 6-8).

Insertion loss is approximately the same whether the equalizer is molded or un-molded. An equalizer's assigned value (e.g., 0.5 dB, 2.0 dB, 4.0 dB, etc.) is based on the approximate insertion loss of the equalizer at low frequencies. For illustration purposes, insertion loss graphs for exemplary 2.0 dB, 3.0 dB, and 4.0 dB equalizers are shown in Figs. 6-8.

Fig. 6 shows insertion loss as a function of frequency for an exemplary 2.0 dB equalizer. The measured insertion loss for various frequencies is stated below in Table 1:

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TABLE 1	
Frequency (MHz)	**Insertion Loss (dB)**
45	-2.216
400	-1.229
600	-0.884
870	-0.762

Fig. 7 shows insertion loss as a function of frequency for an exemplary 3.0 dB equalizer. The measured insertion loss for various frequencies is stated below in Table 2:

TABLE 2	
Frequency (MHz)	**Insertion Loss (dB)**
45	-3.006
400	-1.615
600	-1.090
870	-0.834

Fig. 8 shows insertion loss as a function of frequency for an exemplary 4.0 dB equalizer. The measured insertion loss for various frequencies is stated below in Table 3:

TABLE 3	
Frequency (MHz)	**Insertion Loss (dB)**
45	-3.768
400	-1.970
600	-1.237
870	-0.795

Certain exemplary embodiments of the present invention are two-port devices, with an input, an output, and a ground, and are used in a 75-Ohm environment. The molded equalizer itself is also a 75 Ohm device in order to have a matched system (i.e., both the transmission line and the system component impedance are 75 Ohms). In an ideal system, the entire incoming signal is transmitted through the equalizer. However, in reality, the

transmission line and all of the system components and parts are not an ideal 75 Ohms, and thus not all of the signal power is transferred into the equalizer. Instead, some of the signal is reflected back to the source. Accordingly, return loss is measured on both the input side and the output side of the equalizer (input return loss and output return loss). The goal is to measure a lower power signal coming back from the input side of the equalizer. In fact, the lower the better, with the minimal input and output return loss being –22 dB.

In contrast to insertion loss, return loss of a molded equalizer varies from that of an un-molded equalizer of the same dB value. For each figure 9A, 9B, 10A, 10B, 11A, and 11B, the return loss for an un-molded equalizer is shown by the top line of each graph, while the return loss for a molded equalizer is shown by the bottom line with the trace arrows. The value of return loss is measured at four different frequencies (45, 400, 600, and 870 MHz) within the spectrum used in the CATV industry and those values are reproduced in the tables below for the exemplary molded equalizers.

Fig. 9A shows input return loss as a function of frequency for a 2.0 dB equalizer. Fig. 9B shows output return loss as a function of frequency for a 2.0 dB equalizer. Measured input return loss and output return loss for the 2.0 dB molded equalizer at various frequencies are stated below in Table 4:

TABLE 4		
Frequency (MHz)	**Input Return Loss (dB)**	**Output Return Loss (dB)**
45	-39.96	-38.16
400	-36.24	-29.67
600	-30.80	-26.00
870	-29.00	-24.25

Fig. 10A shows input return loss as a function of frequency for a 3.0 dB equalizer. Fig. 10B shows output return loss as a function of frequency for a 3.0 dB equalizer. Measured input return loss and output return loss for the molded 3.0 dB equalizer at various frequencies are stated below in Table 5:

TABLE 5		
Frequency (MHz)	**Input Return Loss (dB)**	**Output Return Loss (dB)**
45	-35.98	-34.83
400	-38.12	-29.86
600	-30.82	-25.53
870	-28.44	-23.54

Fig. 11A shows input return loss as a function of frequency for a 4.0 dB equalizer. Fig. 11B shows output return loss as a function of frequency for a 4.0 dB equalizer. Measured input return loss and output return loss for the molded 4.0 dB equalizer at various frequencies are stated below in Table 6:

TABLE 6		
Frequency (MHz)	**Input Return Loss (dB)**	**Output Return Loss (dB)**
45	-34.08	-33.04
400	-44.56	-30.51
600	-32.34	-26.35
870	-27.65	-23.70

As shown in Figs. 9A-11B for the exemplary 2.0, 3.0, and 4.0 dB equalizers, the input and output return losses are better for the molded equalizers as compared to the un-molded equalizers of the same dB value. The input and output return losses of the molded equalizers have the desired operating characteristics for use in amplifiers in CATV equipment, while the un-molded 2.0, 3.0, and 4.0 dB equalizers of Figs. 9A-11B do not have the desired

operating characteristics. To obtain the desired operating characteristics, the present invention accounts for adding an injection-molded housing in designing an equalizer circuit of an un-molded equalizer. Indeed, previous equalizers have never used such molding because the resulting housing acts as an electrical component of the equalizer, thereby changing the circuit's performance characteristics.

In an exemplary embodiment, injection molding is used to inject molten plastic into a cavity around the circuit board. The plastic then hardens and encapsulates the equalizer circuit and circuit board. Optionally, the molded plastic may be of different colors or include a logo thereon as an identifier. The injection-molded housing and the circuit are one inseparable piece. In fact, the housing becomes a component of the electrical circuit. The final product is extremely robust and leaves no portion of the electronic components of the circuit exposed in any way. Additionally, the final product is a much smaller part when compared to the prior art equalizers shown in Figs. 1A-3C. In an exemplary embodiment, the plastic used for the injection molding is polypropylene, but other plastics, resins, and the like may be used as well with the effects of each on the circuit being slightly different, as is understood by those skilled in the art.

The addition of the plastic (housing) changes the performance of the equalizer circuit, so pre-mold adjustments are made in order for the molded equalizer (i.e., the final product) to have the desired operating characteristics. The housing acts as a capacitor, adding another active electrical component to the equalizer circuit, and is inseparable from the other components of the circuit. Prior to addition of the injection-molded housing, the equalizer circuit has undesirable operating characteristics and performs poorly because the equalizer circuit is designed to anticipate the effects of the housing that will be later added. Simple

experimentation and trial and error are used to determine such effects. As noted above, the effects may vary with the particular plastic or resin used and this will be discovered through simple experimentation. Examples of the effects of injection molding are shown in Figs. 9A-11B and discussed above.

The foregoing description of the exemplary embodiments of the invention has been presented only for the purposes of illustration and description and is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Many modifications and variations are possible in light of the above teaching.

The embodiments were chosen and described in order to explain the principles of the invention and their practical application so as to enable others skilled in the art to utilize the invention and various embodiments and with various modifications as are suited to the particular use contemplated. Alternative embodiments will become apparent to those skilled in the art to which the present invention pertains without departing from its spirit and scope. Accordingly, the scope of the present invention is defined by the appended claims rather than the foregoing description and the exemplary embodiments described therein.